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Entomostraca and the Surface-film of Water. By D. J. Scourfield. (Communicated by L. C. Miall, F.R.S., F.L.S., Professor of Biology, Yorkshire College, Leeds.)

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(Plates I. & II.)

Although it has long been recognised that the curious physical properties possessed by the surface-film of water render it of considerable importance to many of the smaller aquatic animals, the question of the specific relation of these creatures to the surface-film seems to have been somewhat neglected by naturalists. Many observations have of course been recorded and some valuable suggestions made in this connection, notably those by Prof. L. C. Miall, F.R.S., in his Lectures on "Some Difficulties in the Life of Aquatic Insects" and on "The Surface-film of Water and its relation to the Life of Plants and Animals"*; but nothing that has yet been done can be considered to have exhausted the subject. On the contrary, it is quite certain that a large amount of observational work is still required among all classes of aquatic Invertebrates; and it is mainly as a small contribution towards this end that the following notes and deductions concerning the freshwater Entomostraca are now brought forward. Notwithstanding the necessary in-

* Reported in 'Nature,' vol. xliv. p. 457, and vol. xlvi. p. 7.

clusion of special details and the tentative nature of some of the ideas advanced, it is hoped that the present paper will prove, on the whole, of some general interest.

Neglecting the Phyllopods, which have not been specially studied, and the Copepods, which will be referred to later, the remaining Entomostraca—Cladocera and Ostracoda—present so much in common from the point of view of relation to the surface-film, that it will be convenient to consider them together. For instance, to a large number of animals belonging to both these Orders the surface-film is an ever-present source of danger. It must have been noticed by all collectors of pond-life that whenever a gathering is made containing an abundance of these forms, in a very short time a number of them will be found floating on their sides at the surface in a helpless condition, apparently quite incapable of getting back into the water by their own exertions. From observations made on isolated specimens it appears that the main chance such animals have of regaining their normal habitat lies in moulting. If this be possible to the animals shortly after their misadventure, they can slip back into the water, leaving their cast carapaces still floating at the surface. But if they are not nearly ready to moult, and are also unable to get back by other means, such as violent disturbance of the surface by the wind, for example, it need hardly be pointed out that such an unnatural position can only mean a more or less speedy death. The chief sufferers in this respect, so far as my observations go, seem to be species of the genera *Daphnia*, *Ceriodaphnia*, *Simocephalus*, *Bosmina*, *Eurycercus*, and *Acroperus* among the Cladocera, and of *Cypria*, *Cypris*, and *Herpetocypris* among the Ostracoda, although others also may sometimes be found in this unfortunate state. Judging from the usual paucity of these floating forms on the surface of open waters, it seems probable, however, that, under natural conditions, only a comparatively few lives are sacrificed in this way. But on this point more extended inquiry is necessary before a definite statement can be made. That an enormous number of Water-fleas may occasionally perish from this cause, is clearly shown by the following instance:—During the last summer *Daphnia Schæfferi*, Baird, occurred in astonishing abundance in the London Docks, and when I visited the latter in July there was a dark red scum, composed entirely of these animals, forming a border from 1 to 2 feet in width along the quays, around the ships, &c., and even forming patches of many square yards in the narrow channels connecting the "basins."

Whatever its ultimate value may be found to be as an element in the life-histories of the various species, the means by which this helpless floating at the surface is brought about is well worth examination. That it cannot depend upon any single circumstance seems probable from the following considerations:—(1) The animals, although small, have a decidedly greater specific gravity than water, as can be seen by the way in which they sink upon the stopping of their swimming-organs when not in contact with the surface; (2) they are completely immersed before the floating takes place; and (3) they possess considerable muscular energy, which, if it were not counteracted by other circumstances, would probably take them quickly below the surface. It will be found, I believe, that there are several factors contributing in varying degrees to the observed result. In the first place, the animals subject to this undesirable connection with the surface-film have highly-polished water-repellent shells. This can be directly seen by an examination of floating specimens, and can be further verified by experiment. For instance, if a fair-sized *Daphnia* or *Eurycercus* or *Cypris*, that has been floating, be placed upon a glass slip with a small drop of water, it will be found that a narrow pointed strip of blotting-paper may be applied to the upperside of the animal without getting wet. Under similar conditions, bodies not possessing water-repellent surfaces would have a film of water passing completely over them, and the blotting-paper would therefore draw up a continuous stream. Secondly, it is a well-known fact that when a substance is partly immersed in a liquid which cannot wet it, the surface-film of the liquid is drawn downwards at the line of contact to form a descending capillary curve. The effect of this, as explained in most text-books of physics, is that the surface-film exerts an upward pull upon the body against which the descending capillary curve is formed. By putting these two points together, the first and most important step in the explanation of the floating of these Entomostraca may be made. On the one hand, there are the animals with water-repellent shells, and, on the other, the property of the surface-film to form a capillary depression when in contact with water-repellent substances. The process, therefore, must be as follows:—When an Entomostracan having one of these waterproof jackets happens to pierce the surface-film, a capillary depression is at once formed of such size that it is at least sufficient to sustain the difference in weight between the animal's body and water. In the case of large specimens, the capillary depression can be readily seen with a pocket-lens. In the case of very small forms, e. g. *Bosmina*, it is proved to exist by the way in which they are repelled from a clean glass rod or tube; for it is a familiar fact that while similar capillary curves attract, dissimilar ones repel one another, and the capillary curve formed against glass is of course an ascending one. A very simple experiment may be made which illustrates the whole action on a scale large enough to be watched by ordinary vision. If a lenticular piece of some such water-repellent substance as paraffin-wax be taken, say, about 2 inches in diameter, and weighted until slightly heavier than water, it will be found that as soon as one of its convex faces is pressed from below against the surface-film, the latter rapidly retreats down the sloping sides, producing a large capillary depression, and that the wax then remains suspended from the surface. When it is remembered that, owing to the small size of the Water-fleas, their area, compared with that of the piece of wax, must be enormously greater in proportion to their bulk, it will be seen that the suspending power of the surface-film must also be comparatively greater in their case; for, other things being equal, the force exerted by the surface-film is proportional to the length of the line of contact.

There are two other factors which, although they do not help in the actual floating, are of considerable importance, because together they account very largely for the inability of the animals to get below the surface when once caught by the film. One of these is the tendency which they have, in common with all floating bodies of approximately lenticular shape, to take up a horizontal position, that being their only position of stable equilibrium; and the other, the situation and range of movement of their swimming-organs. The tendency to turn upon their sides is obscured occasionally in consequence of a more or less considerable departure from the lenticular form, or by the possession of wide-spreading antennæ; but it remains true, nevertheless, that in the great majority of cases the animals are actually found floating in this position. It will readily be seen that, when thus floating on their sides, the Cladocera lose the use of one of their swimming-antennæ altogether, it is out of the water, and that both Cladocera and Ostracoda are quite incapable of opposing the upward pull of the capillary depression. The utmost they can do is to move about horizontally at the surface.

There are probably still further factors concerned in the floating, such as the amount of convexity of the shell and its degree of water-repulsion; but these seem only of minor importance, and need not be dealt with here.

Thus far only the danger to which many of the Cladocera and Ostracoda are exposed when accidentally coming into contact with the surface-film has been considered. Attention must now be directed, however, to some cases in which the peculiar properties of the latter have been so utilised as to play quite a normal part in the economy of the animals concerned. It is impossible to say at present to what extent this utilisation prevails, as very few species have been properly examined from this stand-point. The only genuine cases known to me, where special modifications exist adapting the animals for a life in contact with the surface-film, are to be found in the genera *Scapholeberis* among the Cladocera, and *Notodromas* (including the Australian *Newnhamia*, King) among the Ostracoda. I have, it is true, seen species belonging to other genera, e. g. *Simocephalus vetulus*, O. F. M., and *Peracantha truncata*, O. F. M., apparently suspended from the surface; but it seems doubtful if these forms actually make use of the properties of the surface-film; at any rate, they do not present any evident modifications for that purpose. In the British Isles there is but a single representative of each of the two genera mentioned, namely, *Scapholeberis mucronata*, O. F. M. (*Daphnia mucronata*, Baird), and *Notodromas monacha*, O. F. M. (*Cypris monacha*, Baird). These forms, notwithstanding their wide structural differences, have several points in common, correlated, no doubt, with a similar mode of life. But these resemblances will be best appreciated when each species is examined separately in some detail.

Taking, first, *Scapholeberis mucronata*, including both the "acute" and "obtuse rostrata" varieties, it will be seen (Pl. I. figs. 1 and 2) that the most conspicuous of its characteristics are the flattened and straight ventral margin, the two long posterior ventral shell-spines, the elevated position of the eye, the remarkable dark coloration of the shell, and the no less remarkable series of modified setæ on the ventral portions of the valves. Each of these characteristics has doubtless some significance in connection with the subject in hand, but only the two last seem to demand special consideration.

A cursory examination will show that the dark colour alluded to is not distributed uniformly over the whole body, but that it occurs in definite patches. Viewed from the side (Pl. I. fig. 1) there appears a small patch on the ventral face of the head between the eye and the rostrum, another patch covering the ventral third of the valves, which, although not quite reaching the posterior margin, extends into the shell-spines, and a fainter patch along the dorsal line of the body. The small antennæ and the ventral surfaces of all the joints of the large antennæ, together with the pre-anal portion of the post-abdomen, are also evidently darkened. The front or vental view (Pl. I. fig. 2) shows all the above mentioned areas, necessarily with the exception of the dorsal one; and besides revealing the fact that the labrum is also considerably blackened, it proves that the ventral patches of colour are even larger than appeared from the side. A curious little fact may be pointed out in passing, in relation to the patch on the head, namely, that the colour is absent just over the small eye-spot. This seems to show that the latter is really a functional visual organ. The colour in all cases is produced in part by a staining of the chitin, proved by the fact that the moulted shell and appendages retain the characteristic dark areas, and in part by a number of ovoid pigment granules contained in the cells immediately underlying the chitinous integument. These granules are distributed, it is true, all over the surface of the body, but only sparingly in the uncoloured portions, while under the darkened areas they are very abundant. Their colour is not quite black, but rather a dark brown; and this is also the case with the darkened portions of the carapace and appendages. The physiological cause of these peculiar colour-markings is, so far as I am aware, quite unknown. Their probable utility will be seen, however, when the habits of the animal are considered in a later part of this paper.

Passing now to an examination of the setæ fringing the ventral margins of the valves, it will be found that, when looked at from the side (Pl. I. fig. 3), the anterior and posterior members of the series are both longer and coarser than those in the middle. The anterior ones can also be seen to have a small branch directed forward. But beyond this, and the fact that with dark-ground illumination there is an appearance which suggests that an extremely delicate membrane or series of hyaline scales is supported by the setæ, very little more can be made out by examination in this position. To really learn anything of the structure and arrangement of the setæ, they must be viewed from the front, and even then, owing to the thickness and dark colour of the animal, special care is needed to demonstrate the finer details. The setæ arise from a definite flattened area running down the greater portion of the margin of each valve (Pl. II. fig. 1). This area, which is bounded by the edge of the valve and a slight ridge almost parallel to it, represents, no doubt, an original line of hexagonal shell-markings similar to those covering the general surface of the valves. The setæ, it will be noticed, are not alike all the way down, but are divided into three distinct series.

The anterior series (Pl. II. fig. 2) usually comprises about twelve apparently tubular setæ arranged in a single row. The line of their bases occupies a median position on the flattened area for the posterior half of its length; but anteriorly it curves towards the edge of the valve. The first few setæ are directed forward, and at the same time are strongly curved inward; but as the series is followed backward the amount of this curvature decreases, and the general direction of the setæ is also gradually changed, so that those of the posterior half of the series come to point outward. From the base of all except the first two or three setæ, a branch is given off which turns in the opposite direction to that pursued by the main branch; and in nearly all cases each of the branches further gives rise to a little subsidiary outgrowth directed forward. It sometimes happens that the inner branch is widely separated from the other at the base, and then the anterior series practically consists of a double row for a large portion of its length. The last seta is, however, always single, and possesses a short peduncle anterior to its bifurcation. Besides the coarser branching, each seta produces near its distal extremity, and the last also along its posterior margin, a number of exceedingly fine processes, which are usually grouped in bundles of three or four. They can be most easily observed on the last seta (Pl. I. fig. 4); and in this case also a slight break in the edge of the seta can occasionally be seen at their point of origin. From their excessive delicacy it is still uncertain whether these are simple hair-like outgrowths or only corrugations in a hyaline membrane supported by the setæ.

There is yet another point to be noticed in connection with this anterior series of setæ. At some distance beyond the outer branches an excessively faint marking may be seen (see Pl. II. fig. 2) running parallel to a line joining their tips, and consisting of short closely-set lines. I believe this marking is really the outer edge or fringe, so to speak, of a number of imbricated hyaline scales supported by the setæ. This is a point, however, that has not been clearly demonstrated; and the supposition is based mainly upon comparison with the more evident scales found in connection with the middle series of setæ.

In the middle series there is always a distinctly double row of comparatively short and nearly straight setæ, pointing approximately backward, the setæ of the inner line inclining somewhat inward, and those of the outer line outward. They are arranged in pairs, of which there are about twenty; and the bases of the setæ of each pair are joined by a faint ridge. Where the setæ of the inner line project beyond the edge of the valve, they can be seen to support a series of very delicate slightly overlapping scales, the edges of which, under high magnification, have a similar appearance to that noticed just beyond the tips of the setæ of the anterior series. A view of three of these scales is shown on Pl. II. fig. 3. Analogy would lead one to suppose that similar scales would be found supported by the outer line of setæ; and such is actually the case, but these cannot be so readily observed. Probably also the scales of each pair of setæ join in the middle, although this has not hitherto been certainly proved.

The posterior series usually comprises only two setæ, pointing backward, of which the anterior one is bifurcated and the other simple. They are longer than those of the preceding series, but give rise apparently to hyaline scales of identical structure.

Before leaving this subject of the modified ventral setæ, it must be stated that in the male there is only a single row down the whole length of each valve. The setæ are essentially the same in their coarser structure; but they seem to be simply plumose instead of giving rise to hyaline scales. This appearance may nevertheless be produced by a much greater fringing of the edges of the scales than is the case in the female. If not, these male setæ evidently represent a stage in the evolution of the more complicated structures already described.

From the foregoing description, especially of the setæ fringing the ventral margin of each valve, it becomes clear that *Scapholeberis* exhibits very considerable specialisation, and the question naturally arises as to the meaning of the latter. To answer this, attention must be turned to the living animals and their peculiar mode of existence in relation to the surface-film. By watching them in their native ponds, it may be seen, with a little patience, that they have the habit of disporting themselves quite close to the surface, especially in sunny weather; and this fact has been noticed and recorded by many observers. But something more than this seems necessary to justify the elaborate modifications described; and it is therefore particularly fortunate that by very simple means a most intimate connection with the surface-film can be demonstrated. If a single individual be isolated, say, in a watch-glass, and carefully observed, it will be found sooner or later to come up and apply its straight ventral margin close to the underside of the surface-film. In this position it will usually continue to move about more or less rapidly for considerable periods, very often, in fact, until purposely disturbed, when it will at once dive below the surface. Occasionally, when conditions are favourable, the animal may even be seen to remain motionless at the surface, with its swimming-antennæ held rigidly almost at right angles to the body (Pl. I. fig. 2). But what does this mean? Since the animal is heavier than water, it can only mean that the difference in weight between the animal's body and water is borne by the surface-film, and this again further implies the existence of a capillary depression. Such depression can be actually seen if looked for in the following way:—Place the watch-glass containing the specimen in such a position that the light from a lamp or window falls upon the surface of the water at an angle anywhere between 20° and 30° with the horizontal. If the eye, aided by a lens or low power of the microscope, be now placed in the path of the reflected rays, the surface will appear like a sheet of polished silver, upon which the smallest speck of dust or break in continuity can be instantly detected. Now whenever the animal comes into contact with the surface-film, it will be found that there is a very evident break, or rather several breaks, produced in the continuity of the surface-film. Further, these breaks will be found to persist as long as the contact is maintained, no matter whether the animal be actively moving about or stationary. It is not pretended that these minute irregularities in the surface-film can be readily made out to be capillary depressions. They must, however, be either depressions or elevations; and since it is impossible to imagine how the latter could sustain a weight, the conclusion is inevitable that the irregularities seen are actually depressions. But how can capillary depressions be formed by such a small body coming from beneath the surface? So far as I am aware, there is only one way in which a capillary depression can be formed under these conditions, and that is by the piercing of the surface-film by a more or less water-repellent substance. By making the assumptions, therefore, that the minute chitinous ventral setæ and scales are water-repellent, and that they can be forced through the surface-film by the muscular power of the animal, neither of which can be considered a very large assumption, it is manifest that a tolerably clear general notion may be formed of the means by which *Scapholeberis* makes use of the surface-film. The water-repellent scales and setæ, pushed through the film, give rise to a number of capillary depressions (apparently four, produced, I believe, by the anterior and posterior groups of ventral setæ) which are large enough to support the animal, but not too large to prevent it from breaking contact with the surface and retreating below when required. While the principles involved are thus essentially the same as in the case of the helplessly floating forms already referred to, in this instance they are turned to good account by means of special organs of limited extent, the whole arrangement being under the control of the animal.

Coming now to *Notodromas monacha* (Pl. I. figs. 6 and 7) it will be noticed that, from the present point of view, its chief characteristics are the dark coloration of parts of the shell-valves, and their flattened ventral surfaces. These, it will be seen, are precisely analogous characters to those specially noted in *Scapholeberis*.

The colour, although not so arranged as in the Cladoceran, is nevertheless distributed in patches in a very definite manner. On each valve there is a practically continuous band of varying intensity stretching diagonally from the upper part of the anterior margin to near the posterior end of the ventral margin, from whence it turns forward and forms a band along the greater part of the edge of the valve, covering very nearly the whole of the flattened area. Two little isolated patches of colour also usually occur between the principal diagonal band and the posterior margin, just below the median line. It is quite clear, from the arrangement described, that in spite of the approach of a part of the coloration to the dorsal surface anteriorly, the bulk of it is, as in *Scapholeberis*, markedly within the ventral half of the shell. I have not noticed an actual staining of the chitin in this case, but the colour-patches are due to an enormous number of minute dark brown granules closely packed within the cells lying just under the shell, and the hexagonal shape of these cells accounts for the zigzag edge of the darkened areas.

The second point to be detailed in relation to this animal, namely, the flattened ventral margin, is very peculiar and deserves careful attention. Examined from the side nothing can be seen but a perfectly straight edge giving rise to a few slender setæ, but looked at from below it becomes evident at once that this ventral portion of the shell is very much specialised (Pl. II. fig. 4). The main features, as seen when the valves are closed, are thus well described by Prof. G. S. Brady, F.R.S., in his "Monograph of the Recent British Ostracoda" *:—"The ventral surface is bounded by two conspicuous elevated arcuate ridges, one on each valve, which together enclose a flattened lozenge-shaped area. Parallel to the contact-margin of each valve runs another straight but much less conspicuous ridge, which, towards the front, curves outward and joins the external ridge at an acute angle, the union of the two forming a slight elevation, from which a single ridge runs forward, gradually merging in the flattened encircling flange of the anterior border." This account is given in connection with the male, but the arrangement is the same in both sexes, the only difference being that the modified area is comparatively larger in the female than in the male. In addition to the two chitinous ridges, there are also, on the ventral portion of each valve, some lines of simple setæ. By far the longest of these is the one running quite close to and parallel with the inner ridge on its outer side. The others are found in the somewhat semicircular depression formed by the bending of the inner to join the outer ridge, which depression, by the way, is most strikingly similar, both in position and shape, to that found on the anterior part of the shell-valves of *Scapholeberis*.

The habits of *Notodromas* are almost identical with those of

* Transactions of the Linnean Society, vol. xxvi. 1868.

Scapholeberis, at least in so far as they relate to the surface-film, and many authors have long since recorded that animals belonging to this genus often swim about just under the surface. I have myself seen groups of *N. monacha*, in a quiet stream, moving about close under the surface, much in the same way as groups of Whirligig-beetles move about on the surface, though more leisurely. But observations of this sort are not sufficient to reveal much about the exact relation of this species to the surface-film and the specific action of its modified ventral area with the curious ridges. For this purpose the same methods must be used as in the previous case. Close attention to the movements of an isolated specimen will show that although it swims nearly vertically, the moment it touches the surface it assumes a horizontal position, back downwards, thus bringing its straight ventral margin into close contact with the surface-film. This action is obviously precisely similar to that already noticed in *Scapholeberis.* In this position the animal may continue to move about for an indefinite period, usually rather briskly, but sometimes so leisurely that no doubt is left in the observer's mind that the weight of its body is actually supported by the surface-film. To make as sure as possible of this point, the surface can be examined with the reflected beam of light as already described, and then it will be found that little irregularities are formed whenever the animal comes to the surface, and that these last as long as contact is maintained. There are usually three such to be seen—two lateral ones anteriorly, and a median one some distance farther back. Here, again, there can be no reasonable doubt that these little irregularities are really capillary depressions, and that they also must owe their origin to the piercing of the surface-film by the ventral ridges, or rather perhaps only the anterior parts of them, and by the extremities of a pair of feet or the caudal rami. The two assumptions that these parts are water-repellent and that they can be pushed through the surface-film are as necessary here to complete the argument as in the case of *Scapholeberis*, although in regard to the first it may be noted that the general surface of the shell of *Notodromas* can be easily shown to be water-repellent, and this of course greatly increases the probability that the same is true of the ridges.

It is not to be imagined that the explanation just given of the means by which the surface-film is utilised, clears up all the curious problems that suggest themselves in connection with the modifications of the two forms described. No certain answer can be given, for instance, as to the reason for the division of the ventral setæ in *Scapholeberis mucronata* into three sections, or about the function of its shell-spines, although it is almost certain that they are both related in some way or another to the animal's peculiar habits. Again, there is the strange rectangular plate projecting from the posterior end of the ventral margin of the left valve in *Notodromas monacha*; while it seems probable enough that this plate also is related to the use made by the animal of the surface-film, nothing is definitely known about it at present.

Leaving these and similar queries, it will be useful to turn to a consideration of the benefits derived from a close connection with the surface. The most important of these are certainly the support afforded, the probable abundant food-material obtained, and the easiness of respiration. The first is very evident, for, owing to the greater specific gravity of these animals than water, a large amount of muscular effort is required to enable them to maintain themselves at any particular level, apart altogether from making onward or upward progress, and this will naturally be entirely saved by suspension from the surface. In regard to the food-supply, two questions arise which need answering before any special indebtedness of the animals to the surface-film on this account can be demonstrated:—(1) Can particles of food floating on the surface be appropriated? and (2) What is the extent to which such particles occur in that position? The first question can be answered in the affirmative without hesitation. If a little finely-divided material, such as flour, be lightly dusted upon the water, it can be seen, if the animals are watched under the microscope when they come to the surface, that the floating granules are taken between the shell-valves in a continuous stream owing to the current produced by the branchial appendages; and from this stream any particles suitable for food would evidently be picked out in the usual way. The second question is not quite so easily answered. Direct observation does indeed show that a number of small fragments of all descriptions can actually be seen upon the surface of all open waters, especially near their margins, but these would only be available for food to a very small extent by the animals under review, which no doubt depend much more largely upon particles so minute as to be practically invisible to the naked eye. That such minute particles also occur upon the surface of ponds and ditches &c. is, however, rendered fairly certain by the fact that in all situations there is known to be a continuous rain of fine dust, a proportion of which is always organic in origin. There is another source of surface-food particles which must be mentioned, although its value in this case is unknown. Some Bacteria in the zooglœa state often form extensive patches on still surfaces, and these frequently afford a sort of rendezvous for numerous small forms of life such as Rhizopods and Infusoria. On the whole, it seems reasonable to suppose that the surface-film does supply these animals with abundant and varied food-material, for which, too (and this, after all, is the crucial point), there is, so far as is yet known, very little competition. It has occurred to me that this peculiar power of obtaining food from the surface may largely explain why these animals are never seen far from the shore. From their structure it might be supposed that they could live equally well at any part of the surface of a piece of water, no matter how large, and so probably they could if food were equally abundant in all parts. But, owing to the surface-drift produced by movements of the air, the middle portions of the area of even small ponds, if not too much sheltered, are always much cleaner than the marginal portions. The third advantage mentioned, namely the comparative easiness of respiration, following as it does directly from the perfect aeration of the surface-water, demands no special comment.

As a contrast to the foregoing advantages, it should be remarked that there seems to be one very probable disadvantage attaching to this mode of life. It can scarcely be doubted that the animals using the surface-film for the purpose of support are much exposed to the attacks of predaceous insects living upon the surface, such as the Whirligig-beetles (*Gyrinus*). Unfortunately no positive proof of this has yet been obtained. If, however, this view is subsequently substantiated, as seems probable enough, the remarkable darkening of these creatures on and near the ventral surface could then be interpreted as an example of protective coloration, for it can be readily observed that their dark colour renders them very inconspicuous in their normal habitats, when seen from above.

In addition to the several characters in common already given, there is one other which merits a passing notice, depending, as it probably does, largely upon the similar habits of the two species under consideration. It has been observed that in this country both are to be found only during the warmer half of the year *. This is not a very striking fact in the case of *Scapholeberis*, because such a limitation of the period of activity is the rule rather than otherwise among the Cladocera; but it is more noticeable with *Notodromas*, as the Ostracoda do not furnish many other examples of periodicity, and even such occur apparently in the colder, rather than in the warmer, part of the year. It will readily be seen that the periodicity found to exist is very advantageous in both these particular cases, for the power the animals possess of attaching themselves to the surface-film would be nearly useless during most of the winter, owing either to the ice or to the comparatively disturbed state of the surface of the water when not frozen.

The surface-utilising habit is so very peculiar and so strangely limited among the Cladocera and Ostracoda, that any evidence relative to its origin would possess more than ordinary interest. Possibly nothing definite will ever be known about the stages of its evolution, but certain suggestions may be made which seem to throw a little light upon the matter, or at any rate to considerably narrow the problem. In the first place, it appears almost certain that the habit did not arise under marine conditions, because a nearly smooth water-surface is an essential, even now, for its exhibition. Secondly, it is tolerably certain that of freshwater forms only those having approximately straight ventral margins could have been able, in the first instance, to use the surface-film to advantage. This, coupled with the fact that both *Scapholeberis* and *Notodromas* can attach themselves to the sides of a glass vessel with their ventral margins towards the glass, leads me to think that the forms from which the present species have been derived were in the habit of crawling over the surfaces of weeds, &c., much as *Graptoleberis testudinaria*, Fischer, does now, and had been modified in the same direction.

* See Baird's 'Natural History of the British Entomostraca,' pp. 100 and 154. Also the author's paper on "The Entomostraca of Wanstead Park," in the Journal of the Quekett Microscopical Club, ser. 2, vol. v. p. 165.

This assumption is perhaps less necessary in the case of *Notodromas* because of the general prevalence of a nearly straight ventral margin among the Ostracoda, but it is essential for *Scapholeberis*. Thirdly, of freshwater forms having nearly straight ventral margins, only those Cladocera accustomed to swim in a somewhat reversed position, and those Ostracoda swimming in the same way, or at least vertically, could, it would seem, have taken advantage of the surface-film by means of their ventral shell-margins.

There is only one other point that need be mentioned before leaving this part of the subject. It has been pointed out in a previous part of the paper that to many of the Cladocera the surface-film is a source of danger; yet to these very same forms there is one indirect way in which the surface-film is probably beneficial, not perhaps to individuals, but to the species. The envelopes of the ephippial or resting eggs of these creatures possess the same water-repellent power characteristic of the carapaces from which they are developed, and in virtue of this they are often found floating on the surface, although really of greater density than water. By this means their dispersal must be greatly facilitated, and their transmission from pond to pond rendered possible, even without the drying-up of the particular pieces of water in which they are produced.

The relation of the Copepoda to the surface-film of water is all that now remains to be considered. The first fact that presents itself in this connection is that never by any chance can an animal belonging to the freshwater division of this order be found floating on the surface in the helpless condition common among the Cladocera and Ostracoda. This may seem puzzling at first, but the apparent explanation is that the coverings of these Copepods do not repel water. A similar experiment to that already mentioned, where a little strip of blotting-paper was applied to the body of an animal lying in a minute quantity of water on a glass-slip, will prove that the water extends in a film quite over the body of such a form as *Cyclops* or *Diaptomus*. Why it is that with presumably the same covering-material the bodies of some Entomostraca should thus exhibit no power of water-repulsion, while the bodies of others, as already shown, are highly water-repellent, remains quite unknown.

In spite of the foregoing peculiarity of their coats, some Copepods are able to suspend themselves from the surface-film.

I have observed several species of *Cyclops* do this, but there are only two in which the habit appears to be in any degree a constant one, namely *C. signatus*, Koch (not including *C. tenuicornis*, Claus, although this form does sometimes suspend itself from the surface), and *C. prasinus*, Jurine (= *C. magnoctavus*, Cragin). When one of the former is closely watched, it will be seen that the animal suspends itself from the surface by means of the long setæ on the second pair of antennæ, exactly in the same way as it would do from a piece of weed. It should be especially noticed that the action is simply one of suspension, the animal always remaining quite motionless after taking up this position. Under the microscope there will be no difficulty in seeing that the two longest of the terminal setæ of each of the second antennæ have penetrated the surface-film, and are lying upon it for a small part of their length. If the reflected beam of light be used, as previously recommended, it will be found that four minute irregularities in the surface-film exist where the setæ break through.

Since animals of this type are denser than water, though but slightly, these irregularities must be capillary depressions. It follows, therefore, that in all probability the explanation of the surface-using power of these species of *Cyclops* is exactly the same in principle as in the previous cases, notwithstanding that it has not been proved directly that the antennal setæ alluded to are water-repellent. One very curious point must not be omitted in regard to *C. signatus* and *C. prasinus*, as it is one which these forms have in common with *Scapholeberis* and *Notodromas*, but which at the same time distinguishes them from all other species of *Cyclops* known to me. It is that they are normally very dark-coloured, sometimes appearing almost black to the naked eye. The pigment producing this dark colour, while not by any means uniformly distributed over the bodies of these two species, is not so markedly ventral as is the case in either *Scapholeberis* or *Notodromas*. As, however, they do not bring any definite area of their bodies into contact with the surface-film, but simply hang from it obliquely, the view that here also the dark colour is protective may be provisionally accepted. Beyond the support afforded in water free from weeds, and the probable easiness of respiration, it is difficult to see what benefits these species of *Cyclops* derive from their power of clinging to the surface-film. They may, of course, also be able to secure additional morsels of food floating on the surface, but so far this has not been observed.

There is yet another way in which the surface-film is utilised by some Copepods. In these instances the animals do not break the surface at all, but make use of the property which a small drop of water possesses of tenaciously adhering to even vertical and overhanging surfaces of solids, by reason of the tension of its enclosing surface-film. The process by which the animals referred to make use of this property is as follows:—When they attempt, as they often do, to force their way up the side, for instance, of a glass vessel, above the general level of the contained water, they become surrounded by a small quantity of water, which most persistently clings to them and to the glass, thereby binding them, so to speak, to the latter. By means of the support thus afforded, some Copepods can raise themselves up the sides of a glass vessel far above the water, and they no doubt raise themselves in a similar way up the exposed parts of the stems &c. of some water-plants. The forms that do this most constantly are certain species of *Canthocamptus*, e. g. *C. minutus*, O. F. M., and of *Cyclops*, e. g. *C. affinis*, G. O. Sars, and *C. phaleratus*, Koch. The last-named species affords perhaps the best example of all. I have repeatedly watched individuals wriggle their way up the sides of a bottle partly filled with water, until they have reached the underside of the cork, where they would stay for very long periods. It may be said quite confidently that, in captivity at least, this species spends more of its time above than below the water; yet its powers of locomotion in this way are not unlimited, for it is practically unable to force itself over dry surfaces. As to the advantages, disadvantages, and other problems connected with such a semi-aquatic mode of existence, nothing definite is known, and so here for the present the subject must be left.

Briefly summarised, the principal views advanced in this paper are as follows:—(1) To many Entomostraca the surface-film of water is a very dangerous element in their environment. To this category belong large numbers of the Cladocera and Ostracoda. (2) To some others, on the other hand, the surface-film affords peculiar advantages. This class includes, so far as is yet known, only a few specially modified Cladocera and Ostracoda, and some Copepoda, which do not, however, present any apparent structural modifications. (3) In all cases (except where some Copepods possibly make use of the properties of the surface-film to attach themselves to aquatic plants above the general water-level) the relation to the surface-film, whether beneficial or the reverse, depends fundamentally upon the same physical principles, namely, the upward pull of the surface-film when forming a capillary depression, and the possession by the animals of water-repellent shells, ridges, scales, or setæ, capable of penetrating the surface-film and producing capillary depressions.

In conclusion I wish to express my best thanks to Prof. L. C. Miall, F.R.S., for his kind sympathy shown during the progress of this inquiry, and for many helpful suggestions.

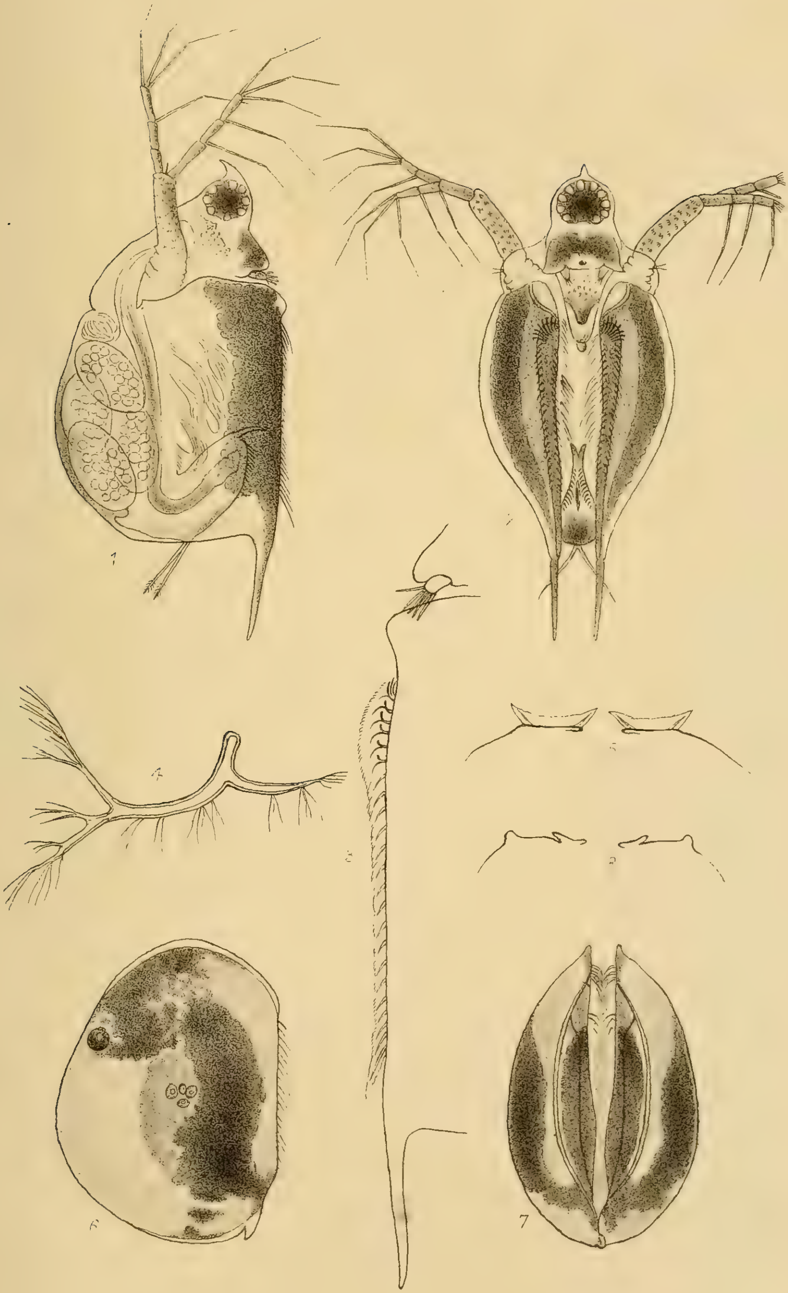
EXPLANATION OF THE PLATES.

Plate I.

Fig. 1. *Scapholeberis mucronata*, ♀. Side view. × 55.
2. The same. Ventral view as seen when in contact with the surface-film. ×55.
3. The same. Ventral margin. ×110.
4. The same. Last of the anterior series of ventral setæ. × 1000.
5. The same. Diagrammatic section across the flattened ventral margins of the valves, showing setæ and hyaline scales.
6. *Notodromas monacha*, ♀. Side view. ×35.
7. The same. Ventral view as seen when in contact with the surface-film. ×35.
8. The same. Diagrammatic section across the flattened ventral margins of the valves showing ridges.

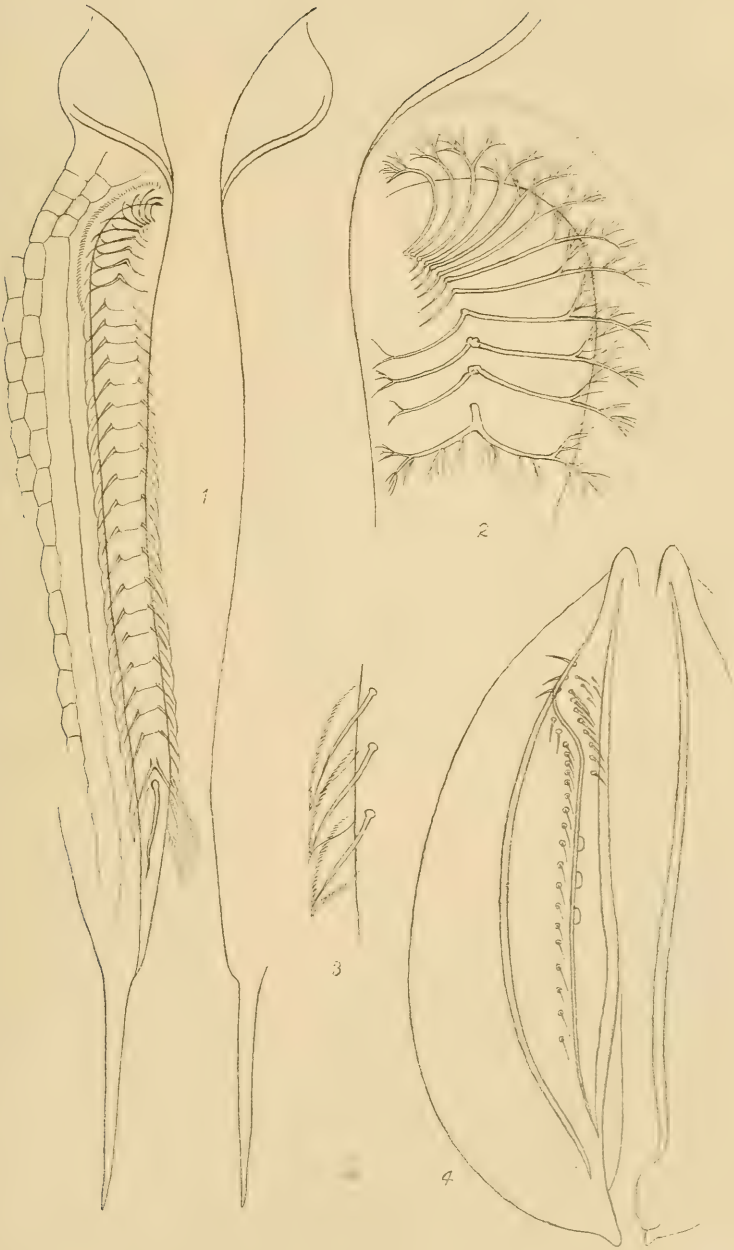
Plate II.

Fig. 1. *Scapholeberis mucronata*, ♀. Front view of ventral margin. ×200.
2. The same. Anterior series of setæ of ventral margin. ×700.
3. The same. Three setæ with hyaline scales from inner row of middle series. ×700.
4. *Notodromas monacha*, ♀. View of ventral flattened area. ×85.



D.J.S. del. A.R. Hammond lith.   Hanhart imp.

1-5. SCAPHOLEBERIS MUCRONATA ♀
6-8 NOTODROMAS MONACHA ♀



D.J.S. del. A.R. Hammond lith.

1-3. SCAPHOLEBERIS MUCRONATA ♀

4. NOTODROMAS MONACHA ♀